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OBSERVATIONS OF DIURNAL AND SHORT-PERIOD EARTH-CURRENT VARIATIONS IN DUSHETI (GEORGIAN SSR)

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/The Dusheti Magnetic Observatory is located 55 kilometers northwest of Tbilisi on the Georgian Military Highway, in the outskirts of Dusheti. Its geographical coordinates are 42° 5' 28" N and 44° 42' 15" E. The station is 981 meters above sea level. The terrain is fairly smooth and part of it is covered with thick undergrowth./

In addition to local stationary currents due to electrofiltration and electrodiffusion, and electrochemical processes, local nonstationary currents or so-called earth currents circulate in the earth's crust and show regular variations during electrical storms. These currents are related to terrestrial magnetism, aurora borealis, and ionospherics, but their exact causes and the nature of their relation to other geophysical and geological phenomena have not yet been established.

Earth currents are of practical as well as theoretical interest, as is illustrated by several examples. A relationship obviously exists between earth currents and earthquake phenomena, which may aid in the forecast of earthquakes and in the explanation of endogenous processes. No attempt has been made to ascertain the role of earth currents in the growth and development of the organic world, particularly the plant kingdom, although it is probable that these internal currents do influence the development of plants. Electrical and magnetic storms markedly affect radio transmission; thus, the study of earth currents and their influence upon radio transmission may help to eliminate noise and improve the quality of radio transmission. The idea of using short-period and high-frequency oscillations of earth currents for geological prospecting is

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highly promising because an artificially created electric field, necessitating cumbersome and expensive equipment, is used in almost all electrical prospecting methods. The utilization of earth currents for this purpose should be studied along two lines: (1) the use of earth currents for calculating resistance variations to determine the geological structure of parts of the earth's crust, and (2) the nature of the currents themselves, especially their short-period component which is possibly connected with the internal state of the earth. The idea of using earth currents in geological prospecting is generally credited to a French scientist, Schlumberger, but actually the Russian scientist, Professor P. Bakhmet'yev, first demonstrated the practical possibilities of using earth currents to measure the resistance of soils.

Earth-current observations were begun early in the twentieth century at several magnetic observatories (Ebro, Huancayo, Watheroo, Slutsk, Irkutsk, Moscow, etc.) and provided accurate observations and reliable scientific results. The earth-current observations begun in Dusheti in 1947 were organized by the Institute of Physics and Geophysics of the Academy of Sciences Georgian SSR. Professors M. Z. Nodia and A. I. Zaborovskiy directed the organization and later the observations of the Dusheti Observatory. Academician N. I. Muskhelishvili, president of the Academy of Sciences Georgian SSR, also aided greatly in the organization of these observations.

Method of Observations and Region under Study

The main element of the earth-current field that is studied is the potential difference between two points of the earth. The method used in previous studies of this type permitted one to determine only the latitudinal and meridional components of the horizontal intensity vector of the earth-current field. Previously, earth currents were observed mainly in long communication lines. Studies of this type are accompanied by great difficulties of a technical and general nature. They do not permit continuous daily records or simultaneous study of the latitudinal and meridional components. However, they do not require highly sensitive equipment and are little affected by nonhomogeneity of the upper layers of the earth and variations of local electric fields.

Short, specially constructed lines, used for the first time in Russia in 1882 - 1883 at the Magnetic Observatory of Pavlovsk, are now preferred for these observations. The main advantage of short lines is that continuous observations can be made. High sensitivity of the registering equipment and detailed study of the area where the stationary equipment is to be placed are required, however, in order to obtain accurate measurements. Location of the stationary equipment when short lines are used must satisfy the following basic specifications: (1) freedom from wandering currents and other electrical interference from power equipment, (2) smooth terrain, and (3) geoelectric homogeneity of the region. Observations made at Dusheti on short lines and the nature of the Magnetic Observatory's environs show that the first two specifications are satisfied. Electrometric studies in the field were made in the summer of 1948 to obtain data for the geoelectric characteristics of the section chosen.

Electrical Characteristics of the Section Where the Stationary Equipment Was To Be Installed

The Dusheti Electrometric Expedition was organized in the summer of 1948 by the Institute of Physics and Geophysics of the Academy of Sciences Georgian SSR under the direction of V. V. Kebuladze to make a detailed electrical survey of the section where the stationary equipment was to be installed. Field studies using the methods for ordinary electric fields, electroprofiling, and electrosounding were made to investigate the natural local electric field and the spatial distribution of the conductivity of rocks. Parametric measurements were also set up at several points.

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Electrometric measurements by these methods were made on 21 lines laid out in the latitudinal direction 50 meters apart. The length of the lines varied from 800 to 1,200 meters, with observation points 40 meters apart. The over-all area for measurements was 1.2 square kilometers.

The resistivity of the rocks in the region under study was investigated by setting up parametric measurements on outcrops with the help of a four-point symmetrical apparatus (AMNB). A total of 60 measurements were made at 24 points, the results of which are shown in Table 1. The rocks in the region of the Dusheti Magnetic Observatory are characterized by the following resistivities (ohms per meter): clay detritus, from 10 to 12; detritus with pebble inclusions, from 30 to 40; clays occurring in their place of origin, from 13 to 25; clays occurring in the place of origin with pebble and limestone detritus inclusions, from 50 to 228.

Table 1. Resistivities of Rocks According to Data from Parametric Measurements

Line No	Name of Rock	Avg Resistivity (ohms/m)
		15.4
W	Clays occurring in their place of origin with pebble inclusions	24.0
E	" " " " " " "	22.8
1'	" " " " " " "	15.8
1"	" " " " " " "	16.8
2'	" " " " " " "	16.8
2"	" " " " " " "	23.7
3	" " " " " " "	16.0
5	" " " " " " "	13.9
6	" " " " " " "	13.5
7	" " " " " " "	20.3
8	" " " " " " "	24.9
9	" " " " " " "	11.6
10	Clay detritus	11.2
19	" "	34.8
17	Detritus with pebble inclusions	59.0
11	Clays occurring in their place of origin with pebble inclusions	95.6
1[illegible]	" " " " " " " " " "	150.0
12	Gravel with clay detritus	154.0
15	Pebbles with clay detritus	228.0
16	" " " "	213.0
14	Firmly cemented conglomerate	128.5
14	Clays occurring in their place of origin with limestone detritus	121.0
18	" " " " " " " " " "	155.0
13	" " " " " " " " " "	

The magnetic field in the region of Dusheti has been studied thoroughly. A micromagnetic survey made by Professor M. Z. Nodia established that the region of the Dusheti Magnetic Observatory is characterized by a normal magnetic field, a condition favoring accurate stationary observations.

The local electric field of the region was studied by the PS method. A total of 1,060 measurements of potential differences were made along the 21 lines.

An analysis of the graphs showing the change of potentials along profile lines showed that there is no local anomalous field of electrochemical, electrofiltration, or electrodiffusion origin in the entire territory where the stationary equipment was to be situated. The electrical potentials did not undergo substantial changes with the exception of the 19th line, where the potentials reached 20 millivolts on a very limited section. On the remaining lines the natural potentials did not exceed 12 millivolts.

The electroprofiling method with dispersions AB = 200 meters and MN = 40 meters was used to survey the area to investigate the distribution of the apparent resistivity (ρ_k). A total of 490 measurements of the apparent resistivity were made.

The results obtained from the observational data indicated that the area can be divided into two parts, namely northern and southern. The northern part is characterized by low values of apparent resistivity not exceeding 20-25 ohms per meter. These resistances apparently correspond to clayey deposits. The southern part is characterized by higher, apparent resistivities, reaching 250 ohms per meter, probably due to the presence of conglomerates and pebble inclusions in clays.

Changing at 26 points the ratio between AB and MN, 545 measurements were made of the apparent resistivity. The maximum dispersion of the transmitting (feeder) electrodes varied from 400 to 800 meters.

The variations in resistivity of the rocks with depth was followed by processing the data obtained in electrosounding. One-strata curves were obtained for the northern part while two-strata curves were obtained for the southern part, thus confirming the electroprofiling results.

The electrometric studies showed that there are no rocks in this area that would give very sharp field nonhomogeneities; thus, the region is suitable from this standpoint for observations of earth currents.

Instruments for Registering Diurnal and Short-Period Variations of the Potential Gradient

The equipment needed to study earth currents is not produced commercially; therefore, it had to be constructed by the scientists engaged in the project. The lack of concrete data on the instruments used complicated the problem; even the order of magnitude of the potential gradients which had to be measured was not known. Despite these difficulties, a fully satisfactory instrument was constructed with the aid of collaborators of the electroradiometric laboratory of the Institute of Physics and Geophysics of the Academy of Sciences Georgian SSR (V. A. Marshev, V. R. Dzhaparidze, and mechanic R. Mayer).

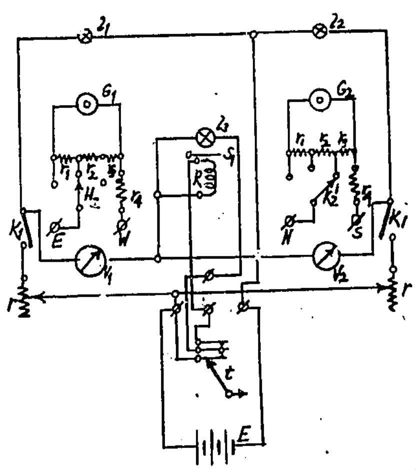

Figure 1. Diagram of the Electrical Part of the Photogalvanograph

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Figure 1 shows the original circuit of the electrical part of this instrument (the photogalvanograph without the register). G_1 and G_2 are similar mirror galvanometers having the following specifications, respectively: sensitivity -- $1.8 \cdot 10^{-8}$ amperes; periods -- 3.2 and 3.4 seconds; internal resistances -- 1,087 and 1,000 ohms; and $r_1 = 150$-, $r_2 = 1{,}850$-, $r_3 = 8{,}000$-ohm galvanometer shunts. These values were selected so that, with a distance of 60 centimeters between the drum of the register and the galvanometers and given a certain value for r_4, it would be possible as need required to produce recordings for three different sensitivities: 10 mV/mm, 1 mV/mm, and 0.2 mV/mm. The resistance r_4 equals 30,000 ohms, namely the external resistance connected in series in the lines; R is a relay; S_1 is the relay armature with a mirror; l_1, l_2, and l_3 are electric lights for illuminating the galvanometers and the relay; r is a filament rheostat with resistances of the order of several tens of ohms; E, W, N, and S are the terminals for connecting leads from the electrodes (lines); t is a clock with contacts; K_1 and K_1' are switches; K_2 and K_2' are sensitivity switches; V_1 and V_2 are direct-current voltmeters for controlling the filament voltage; E are alkaline-type 2.5-volt storage batteries with capacity of 100 ampere-hours for supplying the lights and the relay.

The second important part of the photogalvanograph is the register, the drum of which carries oscillograph paper 12 centimeters wide. The linear speed of the paper is 4 centimeters per hour and thus a complete record for a day is obtained on a tape 96 centimeters long.

Laboratory and field tests demonstrated that this photogalvanograph could be used to register diurnal variations in the potential gradient. With this instrument, the EW (galvanometer G_1) and NS (galvanometer G_2) current components could be simultaneously recorded on the same tape. Depending upon the sensitivity of the photo paper used, the necessary filament voltage for the lights l_1, l_2, and l_3 could be selected through r, V_1, V_2, and E (Figure 1); the switches K_2 and K_2' established the desired sensitivity. The zero lines from which the absolute values of the potential gradients are calculated were plotted on the graphs by a 10-15 minute test at the beginning and end of the day's registration. This was accomplished by closing switches K_1 and K_1' and opening switches K_2 and K_2'. After the zero lines were plotted, the switches K_2 and K_2' were closed, thus switching the galvanometers into the line.

Figure 2 is introduced as an example of a copy of a daily recording to illustrate the nature of the potential gradient curves obtained up to May 1948 with the help of the galvanograph described.

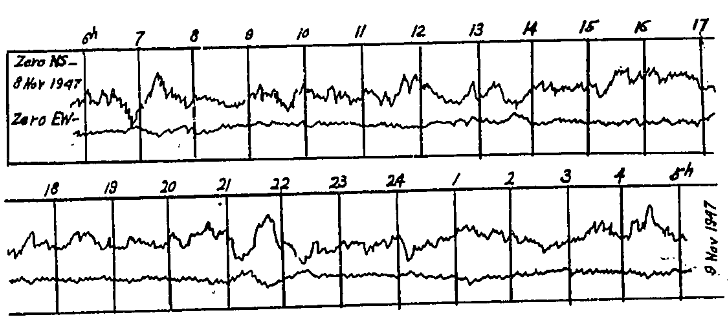

Figure 2. Copy of the Graph of Diurnal Variations in Earth-Current Potential Gradient for 8 November 1947, Greenwich Standard Time.

Sensitivities for the upper curve, 1 mm = 0.95 mV; for the lower curve, 1 mm = 0.76 mV.

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Several changes were introduced in this circuit in May 1948: a register was installed which permitted production of graphs of the diurnal variations in earth-current potential gradient on paper 20 centimeters wide; the speed of the tape was reduced to 2 centimeters per hour; and the sensitivity of the instrument was increased slightly, especially for recording the NS component. After the change, the sensitivity for EW was 0.8 mV/mm, 0.4 mV/mm, and 0.2 mV/mm and for NS it was 0.6 mV/mm, 0.3 mV/mm, and 0.15 mV/mm. Contact clocks of the Variation Pavilion of the Dusheti Magnetic Observatory were used to obtain a reliable time record.

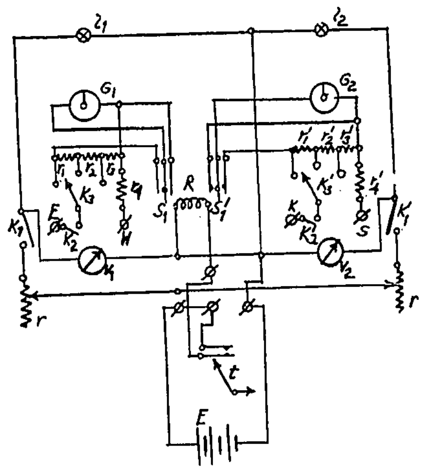

Figure 3. Revised Circuit of Electrical Part of Photogalvanograph

The revised circuit of the photogalvanograph is shown in Figure 3, in which R is a three-contact relay; S_1, S_1' are the relay winding; K_1, K_1', K_2, K_2' are switches; K_3, K_3' are sensitivity switches; resistances (ohms) r_1 equals 1,820; r_2, 1,850; r_3, 3,400; r_1', 2,200; r_2', 2,700; r_3', 4,660; r_4, 52,500; and r_4', 32,800.

A specially selected three-contact relay (Figure 3) was used in the new circuit to obtain the zero lines. With this relay, the dot, indicating the hour also, represents the zero line. As Figure 3 shows, when the clock contacts t are closed, the relay R operates, pulling in the armature and automatically disconnecting the line. The galvanometers are short-circulated and for about 2 minutes an individual dot describing both the hour mark and the zero value of the potential gradient is obtained on the tape.

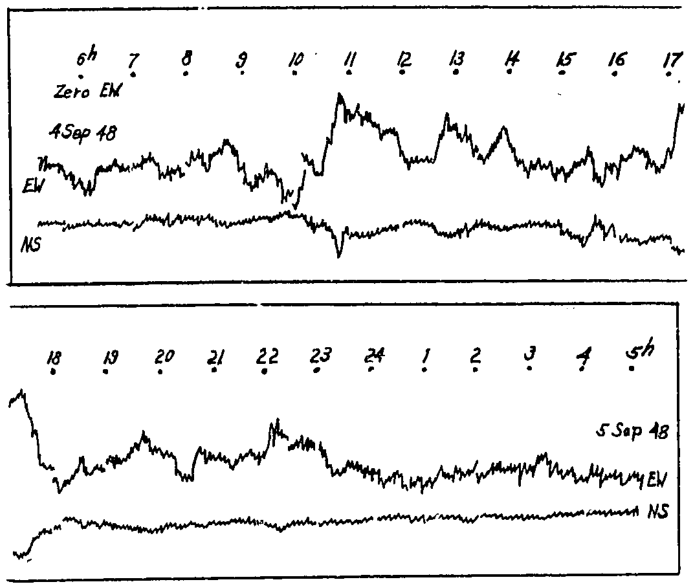

Figure 4. Copy of Graph of Diurnal Variations in Earth Current Potential Gradient for 4 September 1948, Obtained on Revised Photogalvanograph. Greenwich Standard Time.

Sensitivities for upper curve - 1 mm = 0.42 mV; for lower case - 1 mm = 0.72 mV.

It has previously been noted that not only diurnal variations of earth currents but also the so-called short-period variations (from several seconds to tenths and hundredths of a second) were to be registered at Dusheti. Studies of these microvariations are accompanied by many methodological and technical difficulties. Since the amplitude of short-period variations of potential gradients does not exceed several tens of microvolts, highly sensitive equipment with proper frequency characteristics is needed to register them. The construction of an instrument of this type is a complex problem. The photogalvanograph which we constructed, therefore, could not pretend to satisfy completely the aims of these measurements (diagram of this photogalvanograph is shown in Figure 5). The main circuit of the short-period photogalvanograph is the same as that for the photogalvanograph used in diurnal recordings, but the sensitivity and the speed of the tape are increased. It was necessary to add a compensating circuit to the photogalvanograph and devise a suitable register.

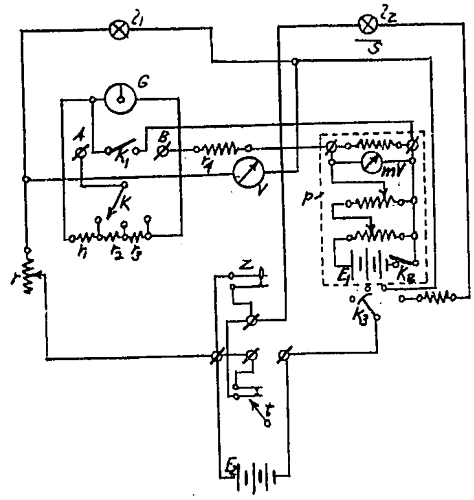

Figure 5. Circuit of the Electrical Part of the Short-Period Photogalvanograph.

In Figure 5, G is a mirror galvanometer of the Leningrad Physics Institute with a sensitivity of $1.3 \cdot 10^{-9}$ amperes (1.3 nanoamperes) with a period of 6.4 seconds and an internal resistance of 546 ohms; P is a circuit for compensating the constant component of the potential gradient during the recordings; A and B are terminals for connecting the lines; l_1 and l_2 are electric lights for illuminating the galvanometer and the mirror S; $r_1 = 2{,}000$, $r_2 = 3{,}000$, and $r_3 = 5{,}000$ ohms are galvanometer shunts. The values of these shunts were determined experimentally so that for a distance of 50 centimeters between the drum of the register and the galvanometer, and also for a certain value of r_4, recordings for three different sensitivities could be made; $r_4 = 5{,}000$ ohms is the external resistance connected in series with the line; V is a direct-current voltmeter for controlling the filament voltage; r is the filament rheostat; K is the sensitivity switch; K_1 and K_2 are line cutout switches; t is a clock with minute contacts; E_1, E_2 are alkaline-type 2.5-volt storage batteries with a capacity of 10 ampere-hours for supplying the lights; z is a key; and K_3 is a transfer switch. The tape could move at the rate of 4, 8, and 16 centimeters per minute. Experimential recordings showed that 4 centimeters per minute was the most suitable speed. At this speed, the mechanism of the register operates for 8 minutes after starting. Oscillograph paper with a maximum width of 12 centimeters could be wound on the drum of the register.

The recordings on the short-period photogalvanograph were made in the following way: Depending upon the sensitivity of the photo paper used, the necessary filament voltage for l_1 could be selected with the help of K_3, r, and V. The register is started and oscillograph paper about 80 centimeters long is wound on one drum and the lever is set at the desired speed. Using A, B, and K_1, the instrument is connected into the line in parallel with the diurnal register. The necessary sensitivity to voltage is established by setting the transfer switch K, and with the help of the compensating circuit P the spot reflected from the galvanometer mirror is directed to the center line of the photo paper. The compensating voltage is read on an accurate millivoltmeter V. The time for starting the recording is noted, and at this moment the mechanism of the register is released using the proper lever. The recording continues for 8 minutes. The minute marks obtained on the tape in the form of small lines also express the zero values of the potential gradients. Recordings of short-period variations obtained by this instrument are shown in Figures 6 and 7 for illustration.

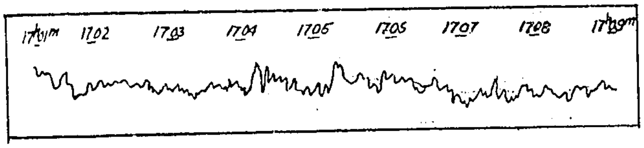

Figure 6. Copy of Graph of Short-Period Variations in Earth-Current Potential Gradient Made for 9 Minutes at 1700 hours, 1 October 1948

NS-component; sensitivity is 1 mm = 0.7 mV, compensation voltage is 40.0 mV. Greenwich Standard Time.

The short-period photogalvanograph and the method of observation require basic improvement and further development. Also, the problem of registering high-frequency variations requires special study. Work in this direction is being conducted at present.

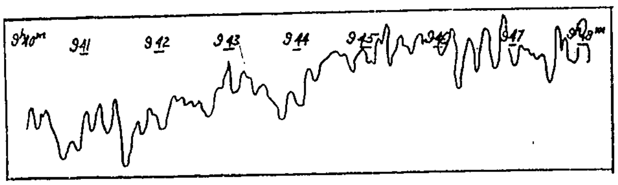

Figure 7. Copy of a Graph of Short-Period Variations in Earth-Current Potential Gradient Made for 8 Minutes at 0900 Hours, 1 October 1948

EW-component; sensitivity is 1 mm = 0.7 mV; compensation voltage is 4.3 mV. Greenwich Standard Time.

Grounds and Lines

The EW line was constructed in September 1947 and the first recording of this component was obtained at this time. The north and south electrodes were grounded and the first recording of the NS component was obtained around the end of October 1947.

In observations of earth currents, both nonpolarizing and metallic (mainly lead) electrodes are used as grounds. The electrodes must have a minimum and constant value of internal emf /electrochemical activity/ and a minimum and constant value of resistance to ground /contact resistance/. Since nonpolarizing /reversible/ electrodes have extremely high transition resistances, lead wire gauze electrodes were used. These were rectangular, 1 x 2 meters, made up from plates 8-10 centimeters wide and 3 millimeters thick. The plates were placed on the horizontal bottom of a specially excavated pit and carefully soldered together there. The lead-out, which is connected to one corner of the rectangular electrode, was passed out through a well-insulated rubber hose coated with tar inside.

All the electrodes, E, W, N, and S, were of the same form and dimensions and were grounded 2 meters from the surface. The N and W electrodes were surrounded by water-permeable clays, and the E and S by clays with pebbles. The electrodes were located at the following absolute distances: E 987.8, W 907.1, N 978.8, and S 912.8 meters. In the summer of 1948, special observations were made to determine the influence of the lead electrodes' internal emf on the recordings. Six nonpolarizing electrodes were prepared, the internal emf of which did not exceed 0.8 mV. Two pairs of three electrodes each connected in parallel were grounded at the western and eastern end of the line at a depth of 1.5 meters, and for 2 days a simultaneous record was made from both the lead and the nonpolarizing electrodes.

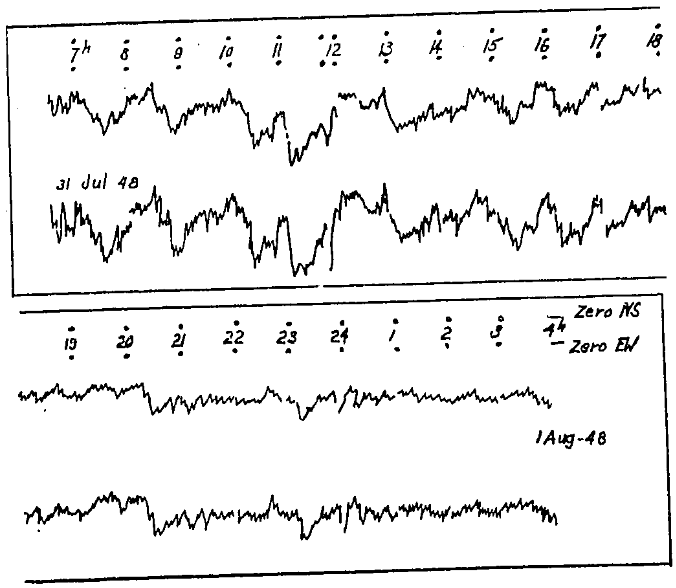

Figure 8. Copies of a Graph of Variations in Earth-Current Potential Gradient with Different Electrodes Used As Grounds

Upper curve: nonpolarizing electrodes; sensitivity 1 mm = 0.64 mV. Lower curve: lead electrodes; sensitivity 1 mm = 0.46 mV. Greenwich Standard Time.

The curves in Figure 8 clearly show the similarity of the recordings obtained from lead and from nonpolarizing electrodes. The comparatively low absolute values of the potential gradient obtained from nonpolarizing electrodes is explained by the fact that the resistance of the entire circuit with the nonpolarizing electrodes (226-230 ohms) is approximately two to three times greater than the resistance of the entire circuit with lead electrodes (102-106 ohms). These experimental recordings thus established the absence of an electrode effect and the good quality of the electrodes used.

The resistance of the entire circuit, including the resistance to ground, cables, registering equipment, and soil, is measured every month to guard against variations in ground resistance. These measurements showed only slight variations in ground resistance. For the past year, the resistance of the entire circuit varied from 100 to 115 ohms for the EW-component and from 115 to 140 ohms for the NS-component. The lines are one kilometer long and coincide with the geographical N - S and E - W lines. Suspension lines using mark PSM cables are used to bring the lines into the pavilion containing the registering equipment. The registering equipment is installed in a small pavilion of the Dusheti Magnetic Observatory which was made available by I. Tsutskiridze, director of the Tbilisi Geophysical Observatory. The construction of a special pavilion in Dusheti for observations of earth currents has now been completed.

Several Results from the 1947 Observations

The daily records for October, November, and December 1947 have been processed fully, resulting in the determination of the average hourly, average daily, and average monthly values for the potential gradients. From this work, tables were drawn up for the potential gradients in units of millivolts per kilometer. According to the generally accepted rule, gradients with positive signs correspond to a current direction from west to east and from south to north; and negative gradients, to reverse directions. Table 2 gives the minimum and maximum average daily values of potential gradients for the 3 months and also indirectly the direction of the latitudinal and meridional components of earth currents in Dusheti for these months.

Table 2

	October		November		December	
Component	Min	Max	Min	Max	Min	Max
EW	-1.4	+6.7	-4.4	-1.8	-4.0	-1.4
NS	--	--	+6.6	+15.1	+0.6	+6.9

The curves of the average daily behavior of the potential gradient, constructed from data for November and December, are shown in Figure 9. The average daily behavior of both components of the potential gradient of the earth current field in Dusheti is characterized by two maxima and two minima. The latitudinal component has a maximum between 0200 and 0300, and 1600 and 1700 hours (local time), and a minimum between 2300 and 0100, and 0800 and 0900 hours. The curves are sinusoidal, and the maxima and main minimum of the latitudinal component coincide closely with the minima and main maximum of the meridional component. The problem of the nonconcurrence of the second maximum of the NS-component with the second minimum of the latitudinal component (they occur approximately 3 hours apart) awaits further study. Another problem is that of the third maximum with a smaller amplitude which occurs between 1100 and 1300 hours and appears particularly clear on the EW curve.

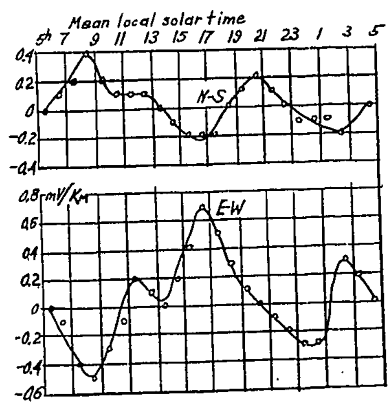

Figure 9. Average Diurnal Variation of the Components of Earth Currents in Dusheti for November and December 1947

The curves were not analyzed in greater detail because it is felt that the 2-month data which has been processed is not sufficient for these purposes. However, one salient characteristic of earth currents is indicated by this meager data. Comparison of these recordings with the magnetograms from the Dusheti Magnetic Observatory show complete parallelism between the behavior of the latitudinal component of the potential gradient of the earth-current field and the horizontal component of the earth's magnetic field intensity. Exceptionally good correspondence of the indicated components is observed not only during magnetic storms but also when the curves are normal. That is, disturbances of the magnetic field and earth currents take place simultaneously.

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The following experiment was performed in the summer of 1948 to check the problem of the influence of variations in the earth's magnetic field upon the registering equipment using a suspension cable: A second cable was laid up to the end of the line under the suspension cable of the latitudinal component. After disconnecting the electrodes and connecting the ends of the cable suspended on columns with the cable laid on the ground, recordings from the closed circuit obtained in this way were made for a period of 3-days. These recordings showed a straight line coinciding with the zero line of the galvanometer and changes in the area enclosed by the circuit did not affect the character of the recordings.

Thus, it was experimentally established that induced emf's, even if they arise in conductors, are so weak that they are not registered by the photogalvanograph. Certain theoretical calculations will be required to estimate the order of magnitude of these emf's.

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